SPRINTARS
(Spectral Radiation-Transport Model for Aerosol Species)

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Simulation of climate response to aerosol direct and indirect effects with aerosol transport-radiation model

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Outline

- Introduction of parameterization for cloud-aerosol interaction based on the Köhler theory into the global aerosol transport-radiation model.
- Simulation including the aerosol direct and indirect effects coupled with a mixed-layer ocean GCM.
- Analysis of change in cloud droplet radius, cloud water, precipitation, and temperature by anthropogenic aerosols.

Model description

SPRINTARS
(Spectral Radiation-Transport Model for Aerosol Species)

Takemura et al. (JGR, 105, 17853-17873, 2000)
Takemura et al. (J. Climate, 15, 333-352, 2002)
Takemura et al. (JGR, in press, 2004JD005029, 2005)

Coupled with CCSR/NIES/FRCGC AGCM

Tracers: black carbon (BC), organic carbon (OC), sulfate, soil dust, sea salt, SO_2, DMS

Emission

- BC, OC: biomass burning, fossil fuel, biofuel, agricultural activity, terpene
- SO_2: fossil fuel, biomass burning, volcano
- DMS: oceanic phytoplankton, land vegetation
- Soil dust: dependence on 10-m height wind, vegetation, soil moisture, snow amount
- Sea salt: dependence on 10-m height wind

Advection

Flux-Form Semi-Lagrangian (FFSL) method
Arakawa-Schubert cumulus convection

Diffusion

Chemical reaction (sulfur)

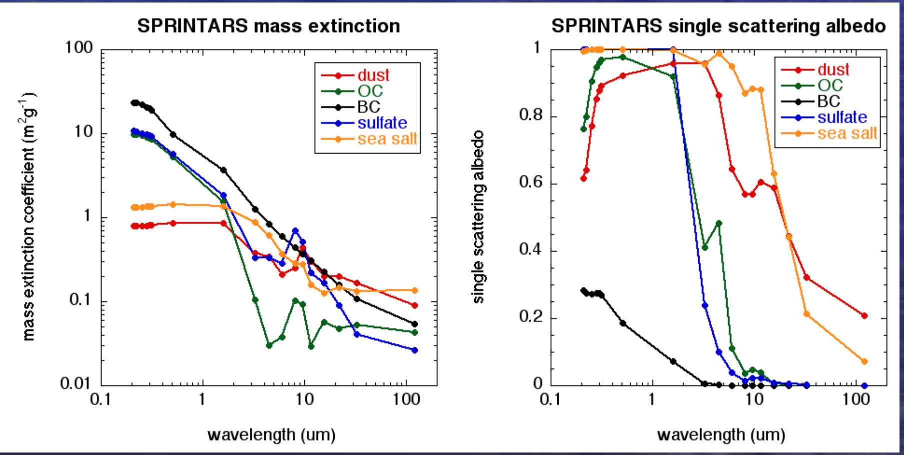
Gas phase: $DMS+OH \rightarrow SO_2$, $SO_2+OH \rightarrow SO_4^{2-}$
Liquid phase: $S(IV)+O_3 \rightarrow SO_4^{2-}$, $S(IV)+H_2O_2 \rightarrow SO_4^{2-}$
»OH, O_3, H_2O_2: CHASER (*Sudo et al. 2002*)

Deposition

Wet deposition (wash out, rain out)
Re-emission by evaporation of rain
Dry deposition
Gravitational settling

Aerosol direct effect

Distinction of refractive indices, size distributions, and hygroscopic growth among aerosol species.



Wavelength dependences of mass extinction efficiency (left) and single scattering albedo (right) for dry particles of each aerosol species.

Aerosol indirect effect

Cloud droplet number concentration N_c

$$N_c = N_a \left[1 + \left\{ f_1(\sigma_a) \left(\frac{A N_a \beta}{3\alpha\omega} \right)^2 + f_2(\sigma_a) \frac{2 A^3 N_a \beta \sqrt{G}}{27 B r_m^{\ 3} (\alpha\omega)^{3/2}} \right\}^{b(\sigma_a)} \right]^{-1}$$

Abdul-Razzak et al. (1998), Ghan et al. (1997)

- N_a: aerosol particle number concentration
- ω: updraft velocity ($= \overline{\omega} + c\sqrt{TKE}$)
- r_m: mode radius of size distribution of aerosol particles
- σ_a: standard deviation of size distribution of aerosol particles
- A: curvature effect
- B: solute effect

Cloud droplet effective radius r_{eff}

→ first indirect effect

$$r_{eff} = k \left(\frac{3}{4\pi\rho_w} \frac{\rho l}{N_c} \right)^{\frac{1}{3}}$$

- ρl: cloud water content
- ρ_w: water density

Precipitation ratio P

→ second indirect effect

$$P = -\frac{dl}{dt} = \frac{\alpha \rho l^2}{\beta + \gamma \frac{N_c}{\rho l}}$$

α, β, γ: constants

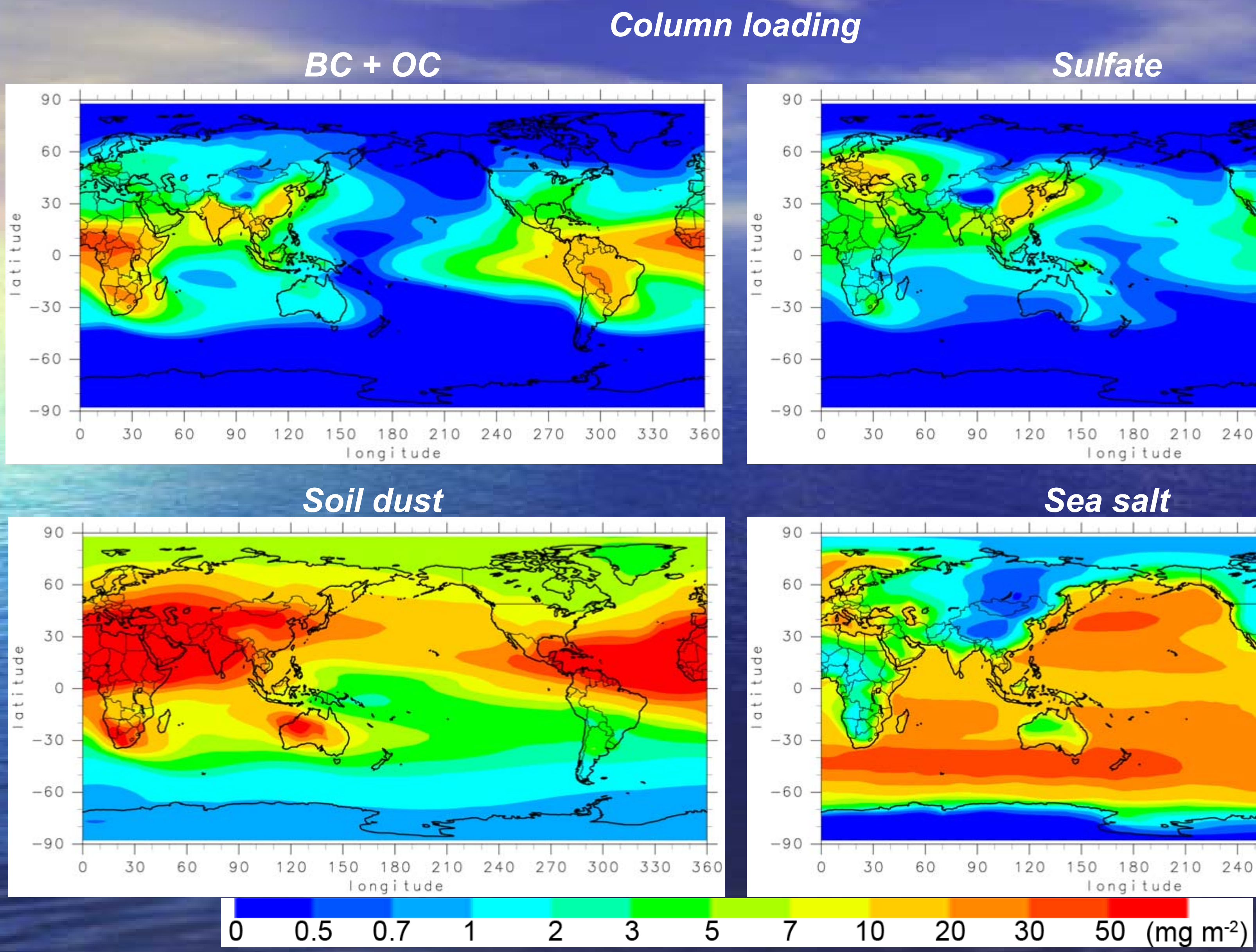
Experimental setting

- Coupled with a mixed-layer ocean model (fixed SST and tropospheric temperature for the forcing calculation).
- 50-year integration → last 30-year analysis (equilibrium experiment).
- Resolution: T42 (approx. 2.8°x2.8°).
- Computer: NEC SX-6 at NIES.
- Present-day (2000) and pre-industrial (1850) aerosol emission runs.

  Anthropogenic emission data from 1850 to 2000 edited by our GCM group (*Nozawa et al.*).

  Greenhouse gases are fixed at the 2000 level.

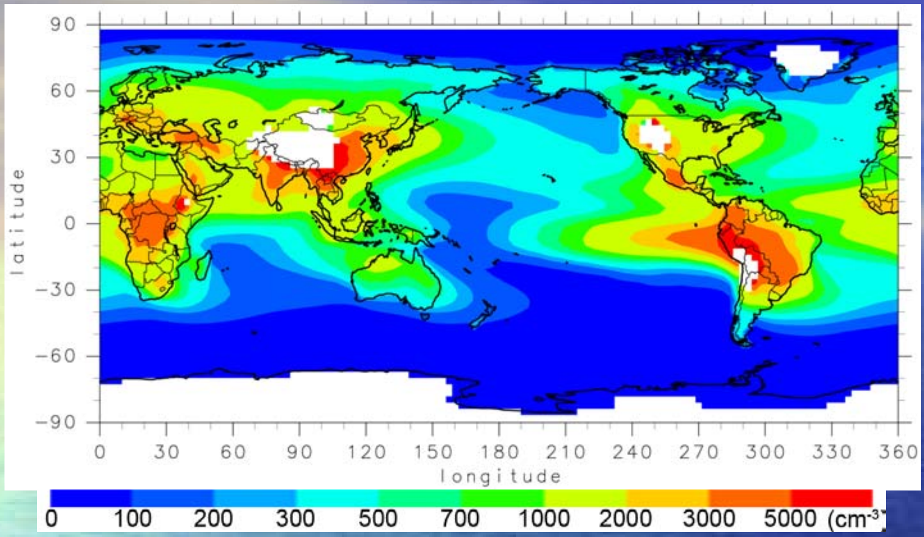
Global aerosol distributions



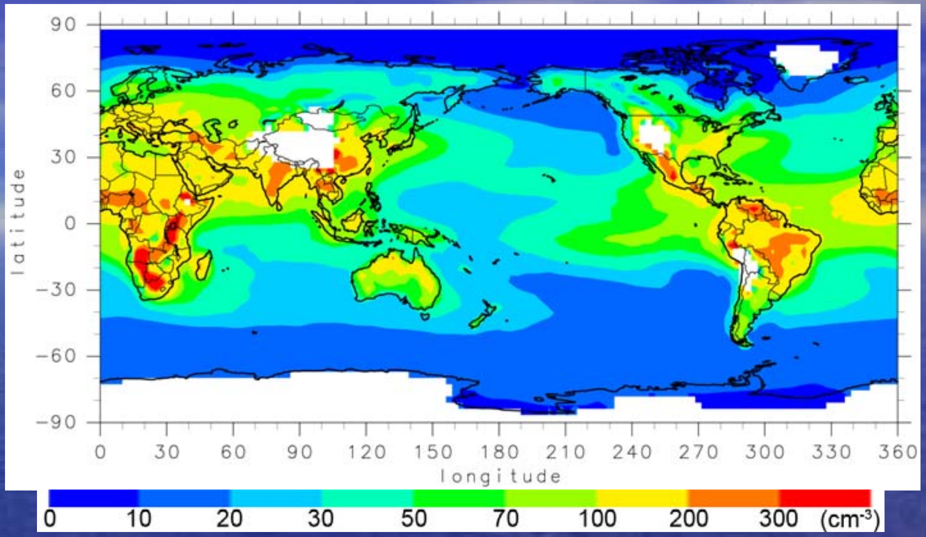
Annual mean distributions of the column loading for each aerosol component.

Cloud droplets and aerosol particles

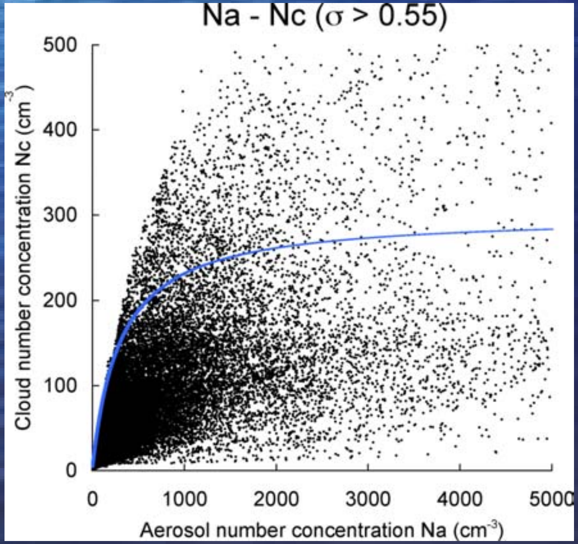
Aerosol particle number concentration



Cloud droplet number concentration



Annual mean distributions of the number concentrations of aerosol particles and cloud droplets at 850 hPa.



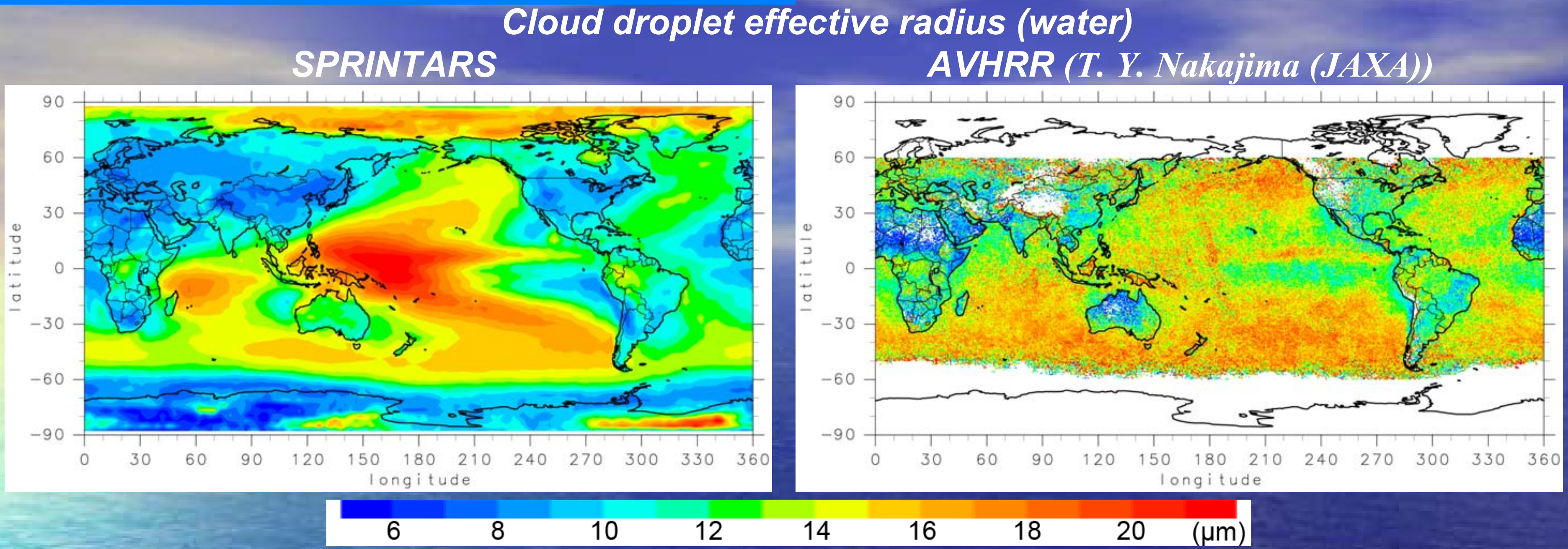
$$N_c = \frac{\varepsilon N_a N_m}{\varepsilon N_a + N_m}$$

ε, N_m: *constants*

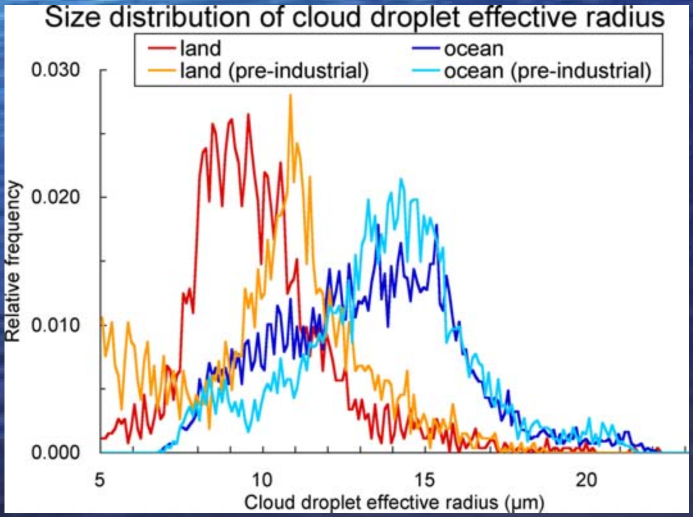
Relationship between the number concentrations of aerosol particles and cloud droplets. Blue line shows the relationship in past studies.

- The relationship disperses due to dependence on the size distribution and chemical property of aerosols and the updraft velocity.

Cloud droplet effective radius



Annual mean distribution of the cloud droplet effective radius at cloud top above the temperature of 273K simulated by SPRINTARS and retrieved from AVHRR.

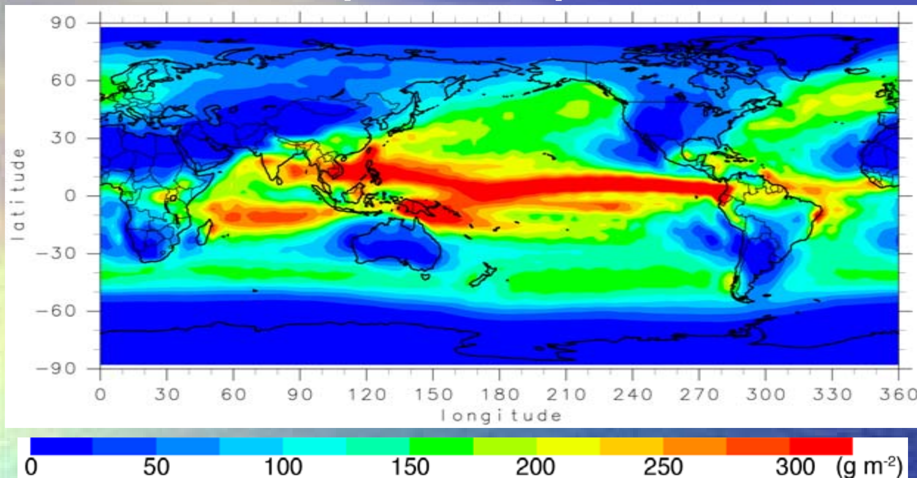


Size distributions of the cloud droplet effective radius at cloud top (T>273K).

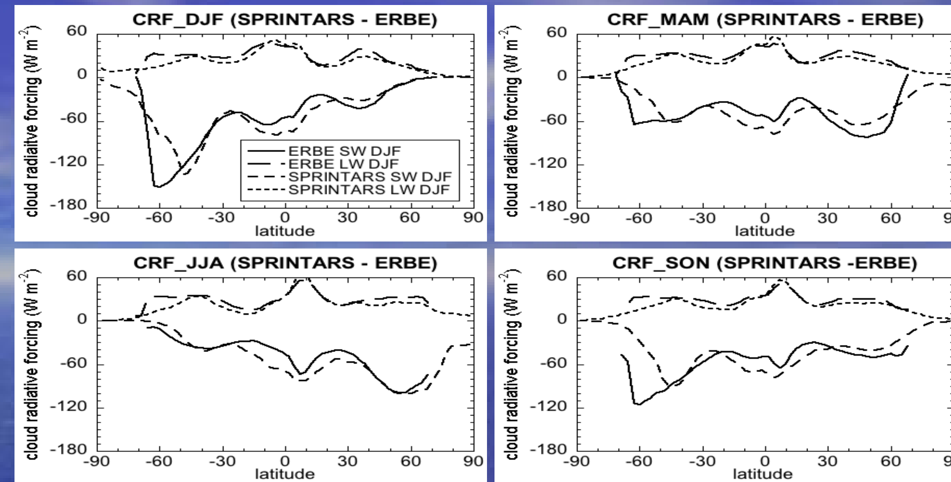
- SPRINTARS simulates land-ocean contrast of the cloud droplet effective radius well.
- Anthropogenic aerosols shift the mode of the cloud droplet effective radius to small size over land.
- Small cloud droplets increase by anthropogenic aerosols also over ocean.

Cloud water and precipitation

Liquid water path

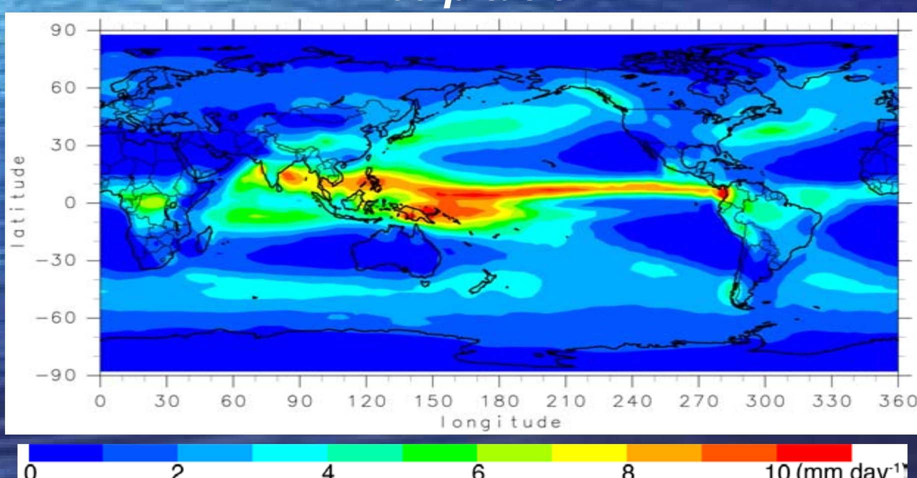


Annual mean distribution of the liquid water path.

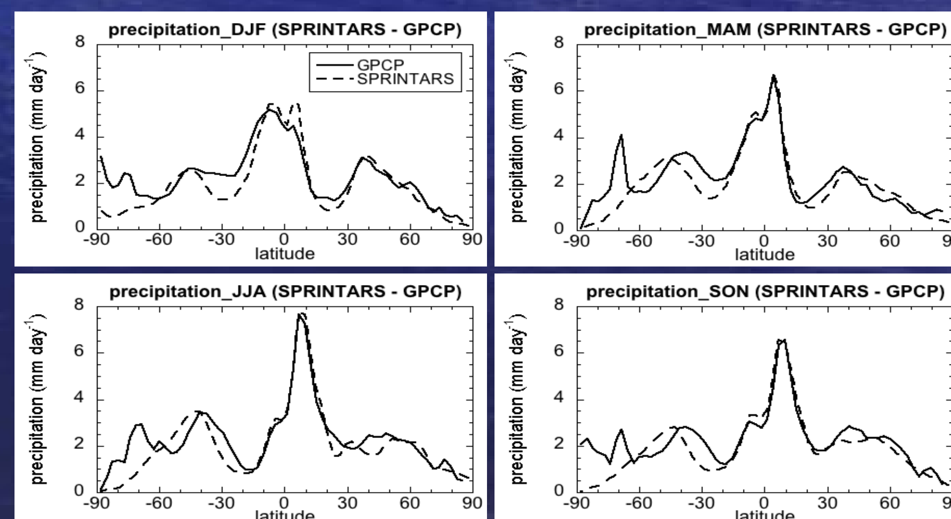


Comparisons of the zonal seasonal mean cloud radiative forcing between SPRINTARS and ERBE.

Precipitation



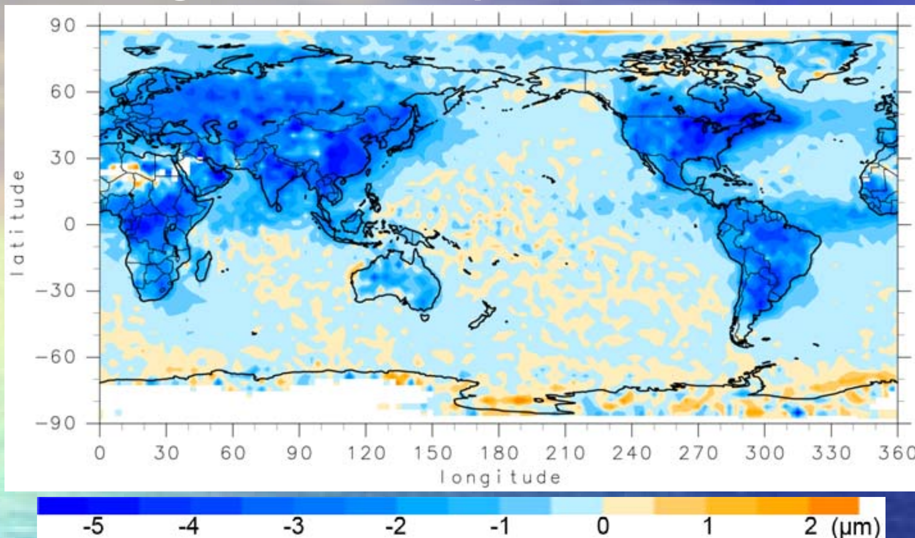
Annual mean distribution of the precipitation.



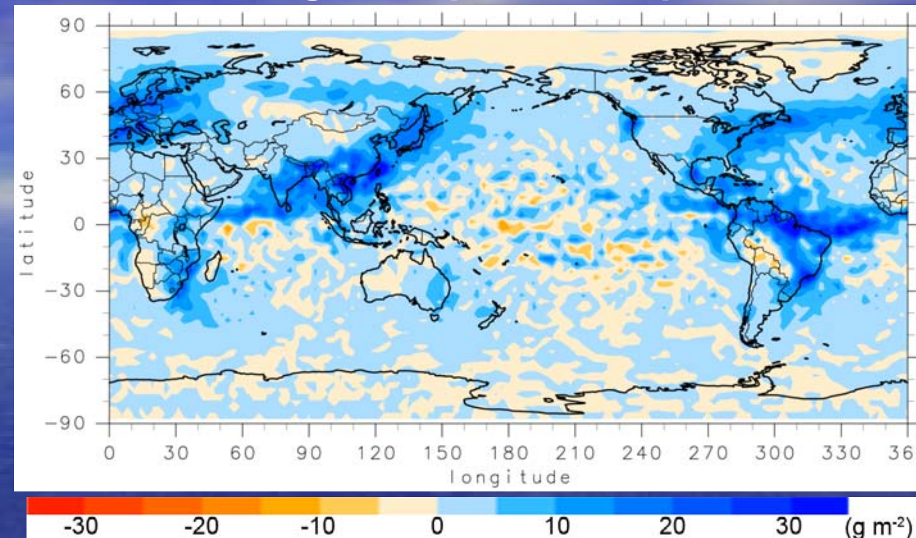
Comparisons of the zonal seasonal mean precipitation between SPRINTARS and GPCP.

Effect of anthropogenic aerosols on cloud and precipitation

Change in cloud droplet effective radius

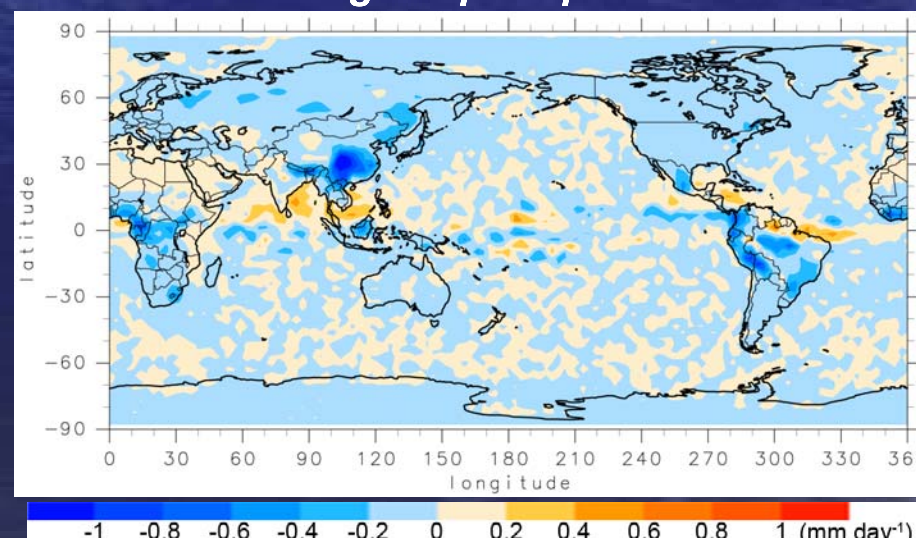


Change in liquid water path



Changes in the cloud droplet effective radius, liquid water path, and precipitation due to anthropogenic aerosols simulated with prescribed SST, wind, and temperature.

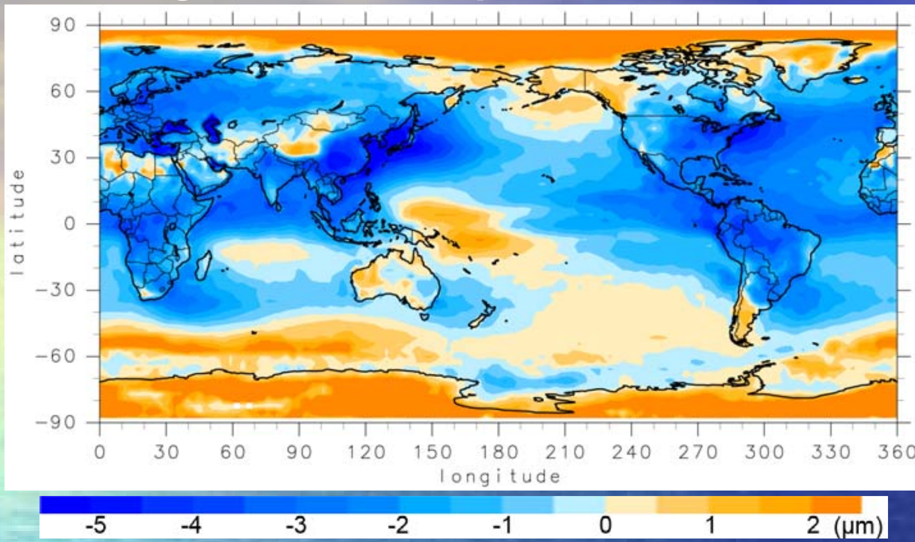
Change in precipitation



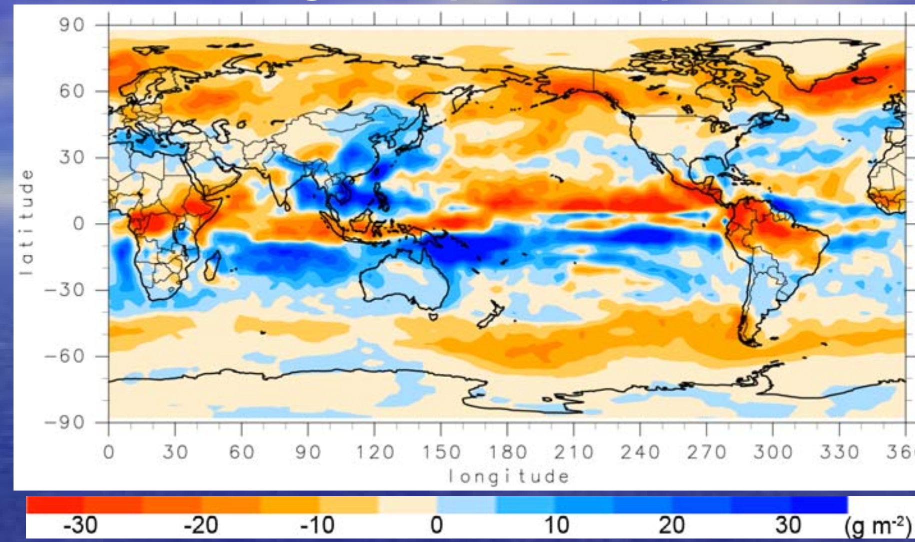
- Anthropogenic aerosols decrease the cloud droplet effective radius (1st indirect effect), increase the cloud water and decrease the precipitation (2nd indirect effect) almost all over the world, especially in industrial and biomass burning regions if the same wind and temperature field are used both in the pre-industrial and present simulations.

Effect of anthropogenic aerosols on cloud and precipitation

Change in cloud droplet effective radius

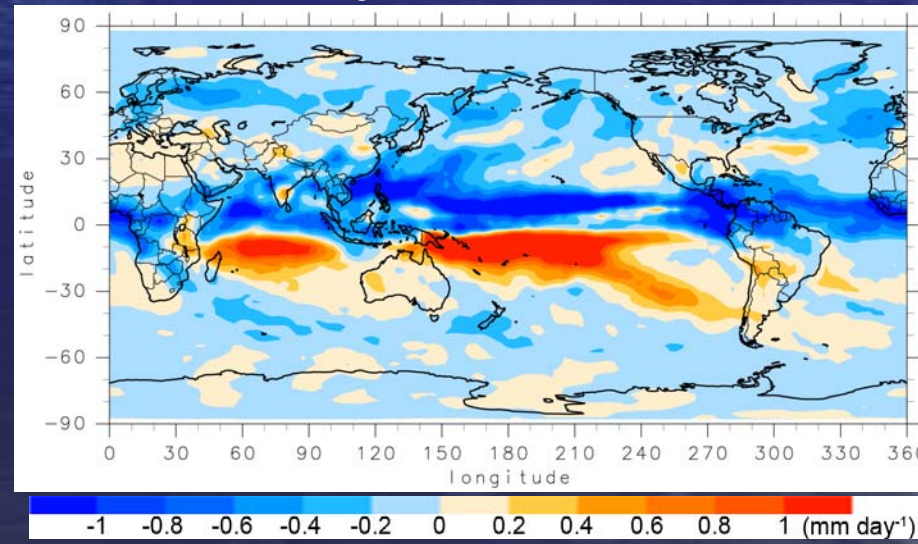


Change in liquid water path



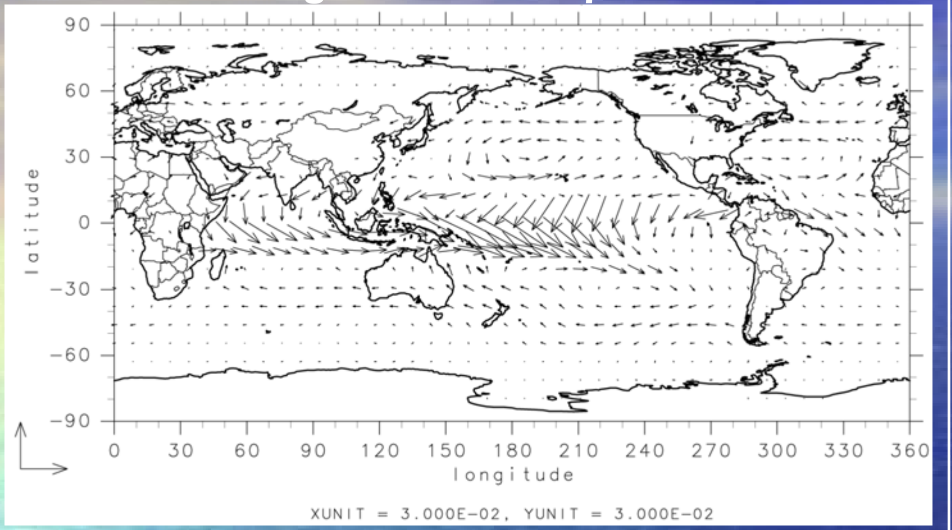
Changes in the cloud droplet effective radius, liquid water path, and precipitation due to anthropogenic aerosols including changes in meteorological field.

Change in precipitation



- Changes in the cloud water and precipitation indicate a change in the hydrological cycle due to the cooling effect by aerosol direct and 1st indirect effects rather than the 2nd indirect effect itself, especially over tropical regions.
- Both an increase in the cloud water and a decrease in the precipitation (2nd indirect effect) is presented over Asia and northern and tropical Atlantic.

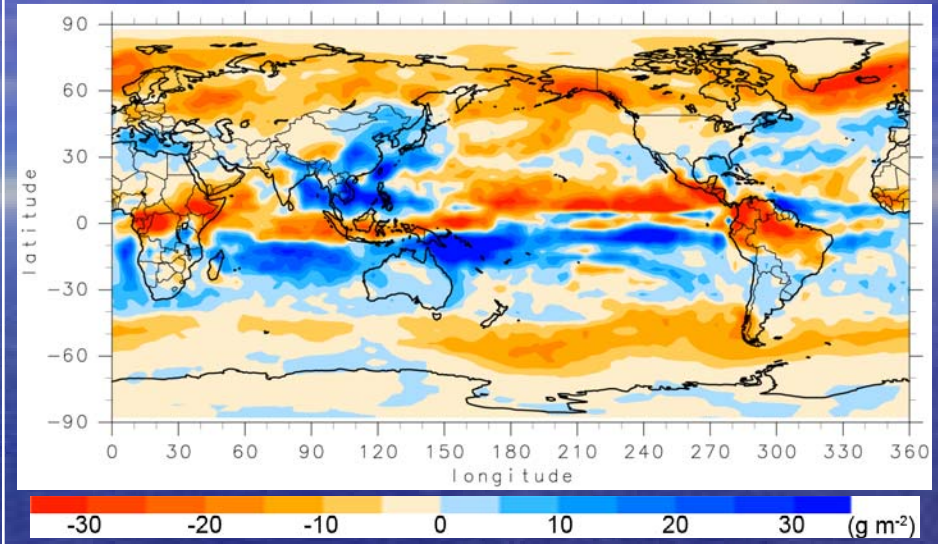
Change in water vapor flux



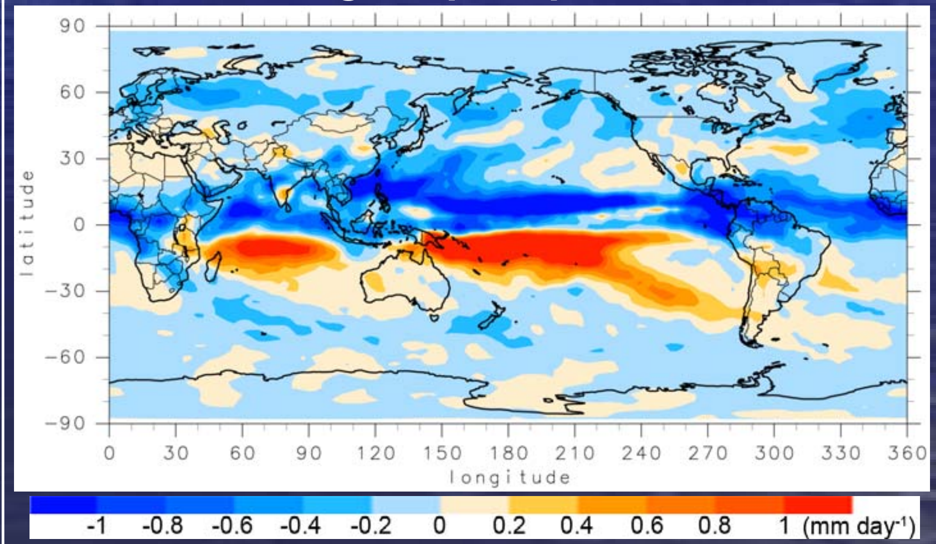
Changes in the horizontal water vapor flux due to anthropogenic aerosols at the lower troposphere.

- An increase (decrease) in liquid water in the southern (northern) tropics is due to the shift of convergence (divergence) of water vapor at the lower troposphere.

Change in liquid water path

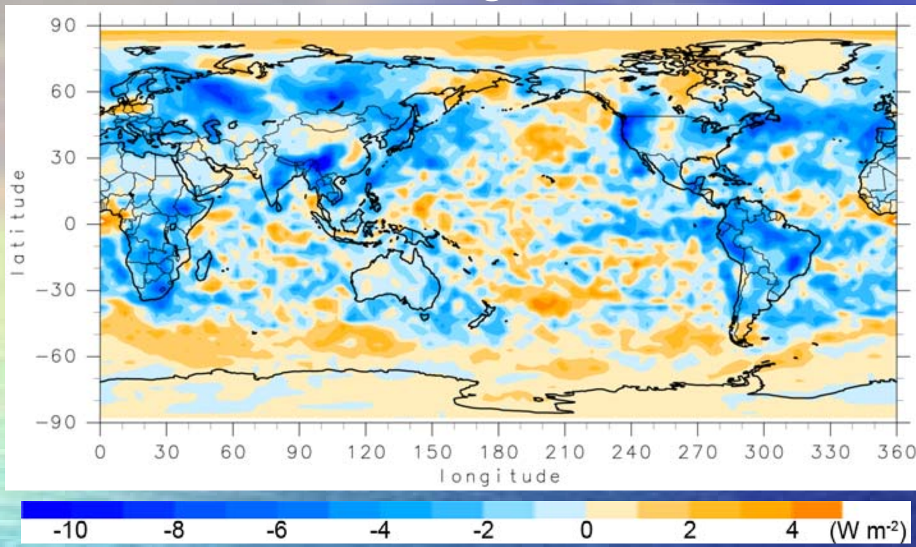


Change in precipitation



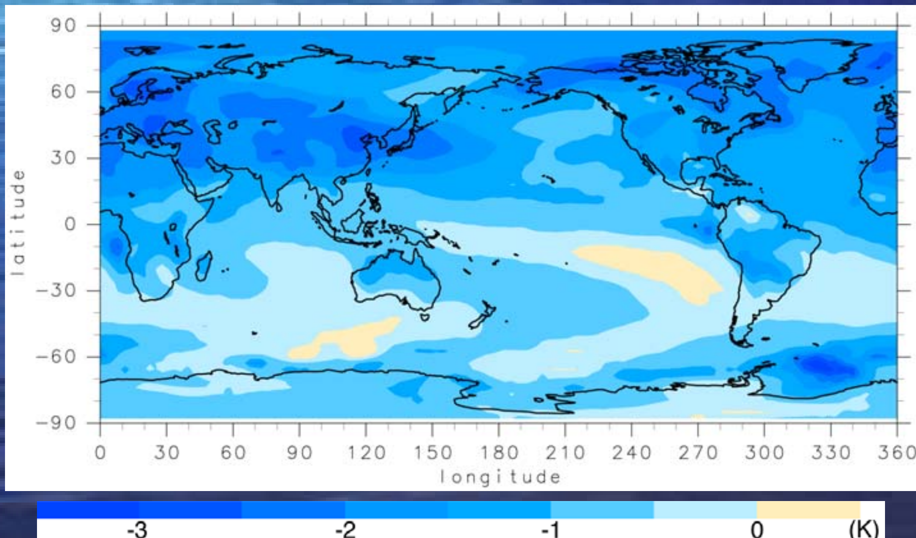
Indirect radiative forcing and temperature change

Indirect radiative forcing ***AVG. –0.94 W m^{-2}***



Annual mean distributions of the indirect radiative forcing at the top of the atmosphere by anthropogenic aerosols.

- The negative forcing is large over northwest Pacific, southeast Asia, Eurasia, North America, South America, and southern Africa.
- The radiative forcing of only the 1st indirect effect (with Sundqvist (1978)) is estimated to be –0.52 W m^{-2}.



Change in the surface air temperature due to the aerosol effects from pre-industrial to present day.

Change in the global mean surface air temperature from 1850 to 2000 by the equilibrium experiment due to

- Aerosol direct and indirect effects: –1.0 K.
- Greenhouse gases: +2.3 K.

→ Anthropogenic aerosols cancel one-third to half of the global warming by greenhouse gases.

Conclusions

SPRINTARS
(Spectral Radiation-Transport Model for Aerosol Species)

Simulation of climate change due to the aerosol direct and indirect effects using the global aerosol transport-radiation model, SPRINTARS, coupled with AGCM including the mixed-layer ocean model.

- Radiative forcing by anthropogenic aerosols: direct … –0.1 W m^{-2}, indirect … –0.9 W m^{-2}.
- Decrease in cloud droplet effective radius due to anthropogenic aerosols (1st indirect effect) is simulated almost all over the world, especially in industrial and biomass burning regions.
- Both an increase in cloud water and a decrease in precipitation due to anthropogenic aerosols (2nd indirect effect) are simulated only in a few regions.
- Anthropogenic aerosols cancel one-third to half of the global warming by greenhouse gases.

The details are in Takemura et al. (JGR, in press, 2004JD005029, 2005).

Change in the surface air temperature from 1850 to 2000 by simulations of CCSR/NIES/FRCGC ocean-atmosphere general circulation model including greenhouse gases and aerosols (RR2002 K-1 project).

- purple: observation
- green: full forcing
- blue: natural forcing only
- red: anthropogenic forcing only
- black: control (forcing in 1850)